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A SOLID FILM LUBRICANT APPLICATIONS GUIDE FOR THE F-18 FINISH SPECIFICATION

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Information is provided on the application of bonded solid film lubricants as a guide for the preparation of an F-18 finish specification. Three major areas are covered which include: 1. corrosion protection relationships, 2. compatibility with liquid lubricants and 3. stripping/rework capability. Requirements for future R&D needs in the area of solid film lubrication are outlined.

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SUMMARY

INTRODUCTION

The need to develop design parameters for solid film lubricants under the F-18 NAVAIRDEVCEN (Naval Air Development Center) Materials Technology Program was made evident in discussions between NAVAIR (Naval Air Systems Command) (AIR-5163C) and NAVAIRDEVCEN. It was considered beneficial to use these design parameters in the preparation of a finish specification for the F-18 aircraft. This information would also be useful for other aircraft applications as well. A program was established at NAVAIRDEVCEN (60612) with the following objectives:

1. To develop laboratory test data on solid film lubricant/corrosion protection relationships.

2. To study the compatibility between solid film lubricant coated specimens and lubricating oils under various conditions.

3. To develop standard procedures for solid film lubricant rework and stripping techniques.

RESULTS

Corrosion Resistance

1. Pretreatment of non-burnished films increases corrosion resistance through better adhesion of the solid film lubricant to the surface.

2. Heat cured resins out-performed air-dry resins.

3. The corrosion environment can attack the substrate through pores in the coating which are created by the lubricating pigments.

4. Films without corrosion inhibitors performed poorly.

5. Burnishing of the solid film lubricant to simulate a worn surface film severly reduces corrosion resistance even when inhibitors are present.

Fluid Compatibility

1. When fluids such as hydraulic or engine oils come in contact with solid film lubricants, degradation of the film is possible.

2. The deleterious effect of fluids is dependent on loading, geometry of bearing surfaces, the type of contaminating oil and possibly speed of moving surfaces.

Stripping and Rework

1. MIL-SPEC paint strippers will remove air-cured resin bonded solid film lubricants from metallic substrates.

2. Sodium silicate bonded (MIL-L-81329) solid film lubricant is readily removed by immersion in boiling water.

3. Heat-cured resin bonded films require the use of either 20% nitric acid at 65°C (150°F) or 20% chromic acid at 93°C (200°F) for removal. Compatibility of the substrate material with these reagents must be determined.

4. If dimensional tolerance of the part is not critical, grit blasting will remove all films.

5. Simple reapplication of solid film lubricant was not adequate to extend wear life at high loads. Pretreatment of the substrate prior to re-application provided increased wear-life. For low load applications, reapplication without further processing may be possible.

RECOMMENDATION

It is recommended that the information contained in this report be utilized in the preparation of the F-18 finish specification covering the use and application of bonded solid film lubricants.

FUTURE R&D REQUIREMENTS

Based on the findings reported in this program and other sources of information the following requirements should be the primary goals of any future R&D programs on solid film lubricants for military aircraft applications:

1. Development of solid film lubricants capable of functioning in the presence of conventional liquid or grease lubricants.

2. Development of a general purpose film whose effectiveness is not dependent on rigid processing controls or surface pretreatments.

3. Development of solid film lubricants that offer adequate corrosion protection when the surface film is disrupted during the "wear-in" process.

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B A C K G R O U N D

A solid lubricant can generally be defined as a material that provides lubrication to two relatively moving surfaces under essentially dry conditions. The most commonly used solid lubricants are graphite and molybdenum disulfide. There are several ways in which solid lubricant powders are employed but the most common is as a solid film. The lubricating powder is mixed with a binder (organic or inorganic) along with other additives and solvents and sprayed onto surfaces to form a thin film. The formulations and spraying techniques are similar to those found in paint technology.

The basic advantages of solid film lubricants are their ability to withstand higher loads than conventional oil or grease lubricants and their ability to maintain their lubricating action over a wider temperature range than conventional lubricants. Thus, it is not surprising that solid film lubricant technology has been utilized in the aircraft and aerospace industry to solve component wear problems.

A survey of NAVAIREWORKFACS (Naval Air Rework Facilities)(1) on the application of solid film lubricant coatings to naval aircraft components has resulted in the following conclusions:

1. Solid film lubricants are generally performing satisfactorily in service as far as their wear life is concerned. Problems can usually be attributed to either poor application techniques or corrosion.

2. Many applications were found where solid film lubricants could replace the current lubrication practice with a considerable saving in rework hours and parts.

3. Research and development which at present is mostly concerned with extended wear life should be redirected toward the following objectives which are more consistent with their utilization:

   a. Oil resistant films
   b. Multi-purpose films
   c. Films which are less sensitive to thickness and pretreatments.

The following military specifications are currently available covering solid lubricant materials:

SS-G-659a	Graphite, Dry (Lubricating)
MIL-M-7866C	Molybdenum Disulphide, Technical, Lubrication Grade
MIL-L-8937C	Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting
MIL-L-23398B	Lubricant, Solid Film, Air Drying, Corrosion Inhibiting

MIL-L-46010A	Lubricant, Solid Film Heat-Cured Corrosion Inhibiting
MIL-L-46147A	Lubricant, Solid Film, Air-Cured (Corrosion-Inhibiting)
MIL-L-81329B	Lubricant, Solid Film, Extreme Environment

Recommended pretreatments for various metallic substrates include:

Steel (except stainless)	Vapor or grit blast, or phosphate MIL-P-16232
Stainless steel	Vapor or grit blast or chemical etch QQ-P-35
Chromium and nickel plating	Vapor or grit blast
Aluminum	Anodize MIL-A-8625 or treat with MIL-C-5541
Magnesium	Anodize MIL-M-45202
Copper and copper alloys	Black oxide MIL-F-495C or bright dip
Titanium and titanium alloys	Vapor or grit blast, or alkaline anodize
Zinc and cadmium plating	Phosphate MIL-P-16232

RESULTS AND DISCUSSION

CORROSION RESISTANCE

Table 1 shows the results of sulfurous acid-salt spray corrosion tests on various solid film lubricants vs. surface pretreatments. Most of the solid film lubricants used in aircraft today incorporate corrosion inhibitors. Specifications utilizing this test require discs coated with solid lubricant to pass four cycles (1 cycle consists of exposure of the disc to salt spray for 2 hours followed by a minimum of 2 hours drying time) with no resultant pitting, visible corrosion, or staining. The following can be noted in Table 1.

1. MIL-L-8937 and MIL-L-23398 both of which contain corrosion inhibitors lasted for at least 4 cycles before failure occurred.

2. MIL-L-81329 which contains MoS_2 and graphite and resin bonded films of either graphite or MoS_2 lasted only one cycle before corrosion occurred. These films did not contain corrosion inhibitors.

3. Pretreatment of the surface increases the number of cycles to failure. This is probably achieved by increased adhesion of the solid lubricant to the surface since uncoated phosphated and vapor blasted surfaces failed during the first cycle.

4. Coating the test disc with only the organic binder provides a pore-free coating lasting for an extended number of cycles. The solid lubricating pigments create pores in the coating through which the corrosive environment can attack the substrate.

5. Burnishing of the solid film lubricant to simulate a worn surface film severely reduces the corrosion resistance properties of the film even when inhibitors are present.

FLUID COMPATIBILITY

In practical applications solid film lubricants are likely to come in contact with liquid or grease lubricants. In general, this condition should be avoided because of the incompatible nature of resin bonded solid film lubricants. Tables 2 through 6 show data generated on two laboratory friction and wear test devices in which MIL-H-83282 hydraulic fluid and MIL-L-23699 turbine engine oil were sprayed onto the test surfaces after a suitable "run-in" period. Base line data is also presented for the undisturbed test. Tables 2 to 5 show the results of Falex tests wherein two stationary V-blocks are loaded against a cylindrical rotating pin. Both test specimens are coated with solid film lubricant. Table 2 covers a MIL-L-8937 coating applied to phosphated steel specimens. After a 20 minute "run-in" period the oil is sprayed directly onto the test specimens while still in motion. At the 4448N (1000 lb.) load both MIL-H-83282 and 23699 caused an immediate failure. The torque rose to over 4 times the steady state value and never recovered. At the lower load of 2224N (500 lb.), failure occurred in only 15 minutes after spraying with MIL-H-83282, however, MIL-H-23699 did not cause an abrupt failure. On the contrary, an abrupt failure was noted for all cases as shown in Table 3 with MIL-L-8937 coated specimens which were vapor blasted prior to coating deposition. Tables 4 and 5 show the results of Falex tests on MIL-L-23398 deposited on phosphated and vapor blasted steel test specimens respectively. The trend is identical to that found for the MIL-L-8937 coating.

Table 6 shows the results of LFW-1 tests on MIL-L-23398 coated phosphated and vapor blasted steel specimens. After a 10,000 cycle (72 RPM) "run-in" period the oil was sprayed onto the surface while the test was still in progress. The LFW-1 providesa different geometry for wear testing in that a cylindrical ring is rotated against a stationary rectangular block. In contrast to the Falex tests, the MIL-L-23699 engine oil caused an abrupt failure while the MIL-H-83282 hydraulic fluid had no detrimental effect. In fact the wear life was several times that of the solid film lubricant by itself. These test were performed at the lower load range 400N (90 lb.) for this test geometry. On closer examination of the MIL-H-83282 tests, it was found that the solid film lubricant had been completely worn off the test ring and that a kind of "grease" had been formed "in-situ" as the test progressed.

It appears from this data that the compatibility of solid film lubricants to contamination with lubricating oils is sensitive to load, geometry of bearing surfaces and the type of contaminating oil. Until resin bonded solid film lubricants are developed which are insensitive to these parameters all precautions for eliminating oil contaminated solid film lubricants in practice should be implemented.

Certain films are available which are nearly pure solid lubricating pigments that are applied by an impingement process by vendors. It is claimed that petroleum fuels, oils and greases may be used in contact with these films. For example, microseal 100-1 (a graphite ceramic) is used on the P-3 generator shaft splines. Also it and Dicronite DL-5 are used on fuel pump bearings in JP5 fuel (2).

STRIPPING AND REWORK

Little information is available on materials which will strip the various type solid film lubricants from metallic substrates. Two techniques which would be useful for this purpose are grit blasting and chemical stripping. While grit blasting will remove all solid film lubricants, chemical strippers were found to be more selective. Ideally, it would be advantageous to use one type of chemical stripping agent for all solid lubricants. Our first approach was to investigate the use of MIL-SPEC paint strippers since these materials are designed to function without deteriorating metal substrates. Our first investigations revealed that the paint strippers listed in Table 7 were effective in removing air dried films of MIL-L-23398 or MIL-L-46147. Removal of the film on 7.6 cm (3 in) x 15.2 cm (6 in) panels was easily accomplished in 10 minutes exposure time. Unfortunately films based on heat cured (MIL-L-8937, MIL-L-46010) resin bonded coatings and sodium silicate (MIL-L-81329) bonded coatings were found to be extremely resistant to the paint strippers.

It was found that 20% nitric acid at 65°C (150°F) or 20% chromic acid at 93°C (200°F) would strip heat cured resin bonded films in about 10 minutes while MIL-L-81329 sodium silicate bonded films could be easily stripped by immersion in boiling water. Of course with the nitric and chromic acid care should be taken to insure that the substrate material is compatible with the acid.

Table 8 shows the results of Falex tests on specimens run for 1 hour after which time the test was stopped in order to rework the test specimens. In one case, the specimens were simply recoated with solid lubricant while the other specimens were grit blasted prior to reapplication of lubricant. The results indicate that a simple reapplication of solid film lubricant was not adequate to extend wear-life. Pretreatment of the substrate prior to reapplication of the lubricant provided increased wear life.

REFERENCES

(1) Peterson, M. B. and Finkin, E. F. "Application of New and Improved Solid Lubricant Materials and Processes to Naval Aircraft" Mechanical Technology, Inc. Report No. 71TR48, 14 Jul 1971

(2) NAVAIREWORKFAC Alameda Local Process Specification 04-2-0300, 23 Aug 1979

TABLE 1. Sulfurous Acid - Salt Spray
Corrosion Test Results (1010 Steel)
(FED Test Method STD 791B Method 5331)

Solid Film Lubricant	Surface Pretreatment (Cycles to Failure) None	Phosphated	Grit Blasted
MIL-L-8937	6	10	9
MIL-L-23398	5	7	5
MIL-L-81329	2	4	4
Graphite/ Organic Binder	2	-	-
MoS_2/ Organic Binder	2	-	-
Organic Binder only (MIL-R-3043)	35+	-	-
MIL-L-8937 Burnished	3	4	2

TABLE 2. Falex Tests on MIL-L-8937 Coated Phosphated Steel Specimens

	Load	
	4448N (1000 lb)	2224N (500 lb)
Base Line, Min.	250	415
MIL-H-83282 sprayed onto surface at 20 min. into run, min. to failure	Immediate Failure	15
MIL-L-23699 sprayed onto surface at 20 min. into run, min. to failure	Immediate Failure	280

TABLE 3. Falex Tests on MIL-L-8937 Coated, Grit Blasted Steel Specimens

	Load	
	4448N (1000 lb)	2224N (500 lb)
Base Line, Min.	205	247
MIL-H-83282 sprayed onto surface at 20 min. into run, min. to failure	Immediate failure	Immediate failure
MIL-L-23699 sprayed onto surface at 20 min. into run, min. to failure	Immediate failure	Immediate failure

TABLE 4. Falex Tests on MIL-L-23398 Coated, Phosphated Steel Specimens

	Load	
	4448N (1000 lb)	2224N (500 lb)
Base Line, Min.	130	---
MIL-H-83282 sprayed onto surface 20 min. into run, min. to failure	Immediate failure	15
MIL-L-23699 sprayed onto surface 20 min. into run, min. to failure	Immediate failure	95

TABLE 5. Falex Tests on MIL-L-23398 Coated, Grit Blasted Steel Specimens

	Load	
	4448N (1000 lb)	2224N (500 lb)
Base Line, Min.	108	---
MIL-H-83282 sprayed onto surface 20 min. into run, min. to failure	Immediate failure	Immediate failure
MIL-L-23699 sprayed onto surface 20 min. into run, min. to failure	Immediate failure	Immediate failure

TABLE 6. LFW-1 Tests on MIL-L-23398 Coated Test Specimens

	400N (90 lb) Load	
	Phosphate	Vapor blasted
Base Line, cyles to failure	54,000	30,000
MIL-H-83282 sprayed onto surface 10,000 cycles into run, cycles to failure	610,000	1,000,000+
MIL-L-23699 sprayed onto surface 10,000 cyles into run, cycles to failure	18,200	10,100

TABLE 7. Strippers for Air Drying Solid Film Lubricants (MIL-L-23398, MIL-L-46147)

Specification	Type
MIL-R-81903	Acid stripper
MIL-R-81294A	Polyurethane
TT-R-248A	Nitrocellulose-acrylic lacquer
MIL-R-81294B	Non-phenolic
MIL-R-81294	Phenolic
MIL-R-81903	Acid, non-phenolic
MIL-R-81294A	Phenolic
MIL-R-81294A	Non-Phenolic
MIL-R-81903AS	Acid Activated

TABLE 8. Falex Tests on Recoated Specimens
(4448N (1000 lb) Load)

Surface Pretreatment	Base Line (Min)	Run 1 hr. Recoated (Min)	Run 1 hr. Grit Blasted Recoated (Min)
	MIL-L-23398		
Grit Blast	160	27	230
Phosphated	120	28	87
	MIL-L-8937		
Grit Blasted	164	24	176